What is claimed is:

CLAIMS

1. An interface mechanism providing motion in at least two degrees of freedom and interfacing motion of a user manipulated object with a computer, said interface mechanism comprising:

a gimbal mechanism including a plurality of members pivotably coupled to each other and providing two revolute degrees of freedom about a single pivot point located remotely from said plurality of members, said pivot point located at about an intersection of axes of rotation of said members; and

a user manipulatable object coupled to at least one of said plurality of members, said user manipulatable object being rotatable in said two revolute degrees of freedom about said pivot point.

2. An interface mechanism as recited in claim 1 wherein said plurality of members includes five members, each of said five members pivotably coupled to at least one of said other five members.

3. An interface mechanism as recited in claim 1 wherein said plurality of members includes five members coupled in a closed loop such that each of said five members is pivotably coupled to two other members of said five members.

4. An interface mechanism as recited in claim 3 wherein said five members includes:

a ground member coupled to a ground surface;

first and second extension members, each extension member being coupled to said ground member;

first and second central members, said first central member having an end coupled to said first extension member and said second central member having an end coupled to said second extension member, wherein said central members are coupled to said linear axis member at ends not coupled to said extension members.

5. An interface mechanism as recited in claim 1 wherein said plurality of members are positioned exclusively on one side of said pivot point, wherein said members are provided within a hemisphere of a sphere defined such that said pivot point is at a center of said sphere and said user

manipulatable object can be moved in a workspace that defines at least at portion of a surface of said sphere.

6 An interface mechanism as recited in claim 3 wherein at least a portion of said user manipulatable object extends through said pivot point.

7. An interface mechanism as recited in claim 6 wherein said user manipulatable object is independently translatable with respect to said gimbal mechanism along a linear third axis in a third degree of freedom through said pivot point.

8. An interface mechanism as recited in claim 3 further comprising a plurality of transducers, each of said transducers coupled between two of said members of said gimbal mechanism for an associated degree of freedom, said transducers being coupled to said computer system.

9. An interface mechanism as recited in claim 8 wherein said transducers include a sensor for sensing the position of said user manipulatable in said two degrees of freedom.

10. An interface mechanism as recited in claim 9 wherein each of said transducers includes an actuator for providing a force on said user manipulatable object in said two degrees of freedom.

11. An interface mechanism as recited in claim 10 wherein motion in said two degrees of freedom is input to a simulation implemented on said computer system.

12. An interface mechanism as recited in claim 11 wherein said simulation is a video game.

13. An interface mechanism as recited in claim 3 wherein said user-manipulatable object includes at least a portion of a medical instrument.

14. An interface mechanism as recited in claim 13 wherein said user-manipulatable object includes a needle having at least a portion of a shaft and a syringe.

15. An interface mechanism as recited in claim 14 further comprising a plunger actuator coupled to said needle for selectively providing a pressure to a plunger of said syringe.

16. An interface mechanism as recited in claim 3 wherein a graspable portion of said user-manipulatable object is approximately centered at said remote pivot point.

17. An interface mechanism as recited in claim 10 further comprising a band drive mechanism coupled between one of said actuators and one of said members, said band drive

mechanism transmitting said force generated by said actuator to said user manipulatable object and transmitting movement applied to said user manipulatable object by a user to said sensors.

18. An interface mechanism as recited in claim 17 wherein said band drive mechanism includes a rotating drum rotatably coupled to one of said members and rigidly coupled to another one of said members, said drum being additionally coupled to a spindle by a flat band, wherein said transducer is operative to rotate said spindle and thereby rotate said drum and transmit force to said member with substantially no backlash.

19. An interface mechanism as recited in claim 18 further comprising a second band drive mechanism coupled between a second one of said actuators and said user manipulatable object, said second band drive mechanism transmitting a force generated by said second actuator to said user manipulatable object in said linear degree of freedom.

20. An interface mechanism as recited in claim 10 wherein said actuators are grounded.

21. An interface mechanism for interfacing motion with a computer system, said interface mechanism comprising:

a plurality of members movable with respect to each other for providing at least one degree of freedom to a user manipulatable object;

an actuator for providing a force in one of said degrees of freedom of said user-manipulable object;

a sensor for sensing positions of said user-manipulatable object in said at least one degree of freedom; and

a band drive mechanism, said band drive mechanism including a capstan and a flat band, said capstan coupled to a particular one of said members and to a rotating shaft of said actuator, wherein said capstan is coupled to said particular member by said flat band such that force is applied to said particular member in said at least one degree of freedom when said rotating shaft of said actuator is rotated.

22. An interface mechanism as recited in claim 21 wherein said force is applied to said particular member in a linear degree of freedom.

23. An interface mechanism as recited in claim 21 wherein said force is applied to said particular member in a rotary degree of freedom.

24. An interface mechanism as recited in claim 21 wherein said flat band includes two separate bands, wherein each of said bands is coupled to said capstan at first ends and each of said bands is attached to said particular member at a second end.

25. An interface mechanism as recited in claim 23 further comprising a drum rigidly coupled to said particular member and rotatably coupled to another one of said plurality of members, wherein said capstan is coupled to said drum by said flat band.

26. An interface mechanism as recited in claim 25 wherein said particular member is one of five rotatably coupled members provided in a closed loop chain such that each of said members is rotatably coupled to two others of said members.

27. An interface mechanism as recited in claim 26 wherein said actuator is grounded.

28. An interface mechanism as recited in claim 27 wherein said plurality of members provide two revolute degrees of freedom to said user manipulatable object about a pivot point located remotely from said plurality of members, said pivot point located at about an intersection of axes of rotation of said members.

29. An interface mechanism as recited in claim 28 wherein said user manipulatable object extends through said pivot point and is movable in said two degrees of freedom.

30. An interface mechanism as recited in claim 29 wherein said user manipulatable object is coupled to a linear axis member, wherein said user manipulatable object and said linear axis member are movable in a third linear degree of freedom.

31. An interface mechanism as recited in claim 30 further comprising a second band drive mechanism including a second capstan and a second flat band, said second capstan coupled to said linear axis member by a flat band and to a rotating shaft of said actuator, such that force is applied to said user manipulatable object in said third linear degree of freedom when said rotating shaft of said actuator is rotated.

32. An interface mechanism as recited in claim 30 wherein said linear axis member is a slide portion of a linear bearing.

33. An interface mechanism as recited in claim 21 wherein said computer system implements a medical simulation and wherein said user-manipulable object is a medical instrument.

34. An interface mechanism as recited in claim 33 wherein said user manipulatable object includes a needle and syringe, and wherein said medical simulation simulates an epidural anesthesia procedure of inserting said needle into tissue, where forces are provided on said needle to realistically simulate said insertion.

35. A method for providing a simulation using a computer system and an interface apparatus, the method comprising:

providing an interface apparatus coupled to a user manipulatable object, said interface apparatus including a gimbal mechanism that allows said user manipulatable object two rotary degrees of freedom in a spherical workspace, wherein said user manipulatable object may be rotated about a pivot point remote from said gimbal mechanism and located at a center of a sphere defined by said spherical workspace, and wherein said interface apparatus also allows said user manipulatable object in a third linear degree of freedom through said remote pivot point;

determining on a computer system the position of said user manipulatable object in at least said linear degree of freedom from a sensor included on an interface apparatus; and

outputting a force on said user manipulatable object using an actuator coupled to said interface apparatus.

36. A method as recited in claim 35 wherein said interface apparatus is entirely on one side of a plane intersecting said pivot point such that said user manipulatable object is on the other side of said plane from said interface apparatus.

37. A method as recited in claim 36 wherein said interface apparatus includes a closed loop spherical mechanism for providing said two rotary degrees of freedom to said user manipulatable object about said remote point.

38. A method as recited in claim 37 further comprising transmitting said forces from said actuator to said user manipulatable object using a band drive mechanism including a capstan coupled to said actuator and a flat band coupling said capstan to said spherical mechanism.

39. A method as recited in claim 35 further comprising a step of outputting forces from said actuators to compensate for the gravitational force resulting from the weight of at least one of said actuators and to allow said user manipulatable object to be manipulated free from said gravitational force.

40. A method as recited in claim 39 wherein said determining the position of said user manipulatable object includes determining whether said user manipulatable object is positioned within simulated tissue of a simulated patient.

41. A method as recited in claim 35 further comprising:

selecting a physical property profile used for determining forces on said user manipulatable object, wherein said physical property profile includes a plurality of predetermined physical property values, and wherein said selection of said physical property profile is based on a position of said user manipulatable object in said at least said linear degree of freedom, wherein said force output on said user manipulatable object is determined, at least in part, from a physical property value of said selected physical property profile.

42. A method as recited in claim 41 wherein said selection of said physical property profile includes selecting from a plurality of available physical property profiles, and wherein said selection is also dependent on a direction of movement of said user manipulatable object along said linear axis.

43. A method as recited in claim 42 wherein said medical simulation is a epidural anesthesia simulation, wherein said user manipulatable object includes a needle having a syringe, and wherein different physical property profiles are selected based on whether said needle is advancing or retracting in said simulated tissue of said simulated patient.

44. A method as recited in claim 42 wherein said physical property profile is selected additionally based on a trajectory of said needle within said tissue.

45. A method as recited in claim 44 wherein one of said selected physical property profiles is used to determine forces simulating said needle encountering a bone.

46. A mechanism for providing motion in at least two degrees of freedom, said mechanism comprising:

a linear axis member able to move in two revolute degrees of freedom in a spherical workspace; and

a gimbal mechanism coupled to said linear axis member, said gimabl mechanism including a plurality of members pivotably coupled to each other and providing said two revolute degrees of freedom for said linear axis member about a pivot point located remotely from said plurality of members, said pivot point located at about an intersection of axes of rotation of said members at a center of a sphere defined by said spherical workspace.

47. A mechanism as recited in claim 46 wherein said linear axis member extends through said remote pivot point.

48. A mechanism as recited in claim 47 wherein said gimbal mechanism is entirely on one side of a plane intersecting said remote pivot point such that at least a portion of said linear axis member is on the other side of said plane from said gimbal mechanism.

49. A mechanism as recited in claim 48 wherein said plurality of members includes five members coupled in a closed loop such that each of said five members is pivotably coupled to two other members of said five members.

50. A mechanism as recited in claim 49 wherein said linear axis member includes a user manipulatable object such that a portion of said user manipulatable object that is graspable by said user is located on said other side of said plane from said gimbal mechanism.

51. A mechanism as recited in claim 50 wherein a grippable portion of said user manipulatable object is centered at said pivot point.

52. A mechanism as recited in claim 50 wherein said user manipulatable object is independently translatable with respect to said gimbal mechanism along a linear third axis in a third degree of freedom approximately through said remote pivot point.

53. A mechanism as recited in claim 50 further comprising a plurality of transducers, each of said transducers being coupled between two of said members of said gimbal mechanism for an associated degree of freedom, said transducers being coupled to a computer system, wherein each of said transducers includes a sensor for sensing the position of said user manipulatable object in said associated degree of freedom and an actuator for providing a force on said user manipulatable object in said associated degree of freedom.

54 A mechanism as recited in claim 50 wherein said user manipulatable object is provided with an additional rotary degree of freedom about a linear third axis parallel to said linear axis member such that said user manipulatable object has three rotary degees of freedom approximately about said pivot point.

55. A mechanism as recited in claim 54 wherein said mechanism is coupled to a computer system to interface motion of said user manipulatable object to said computer system, wherein said three rotary degrees of freedom correspond to roll, pitch, and yaw degrees of freedom, and wherein said roll, pitch, and yaw are mapped to a simuation implemented by said computer system where movement in said roll, pitch, and yaw degrees of freedom control roll, pitch, and yaw, respectively, of a computer object in said simulation.